Applied Antineutrino Physics Workshop
Livermore

Safeguards activities within Double Chooz

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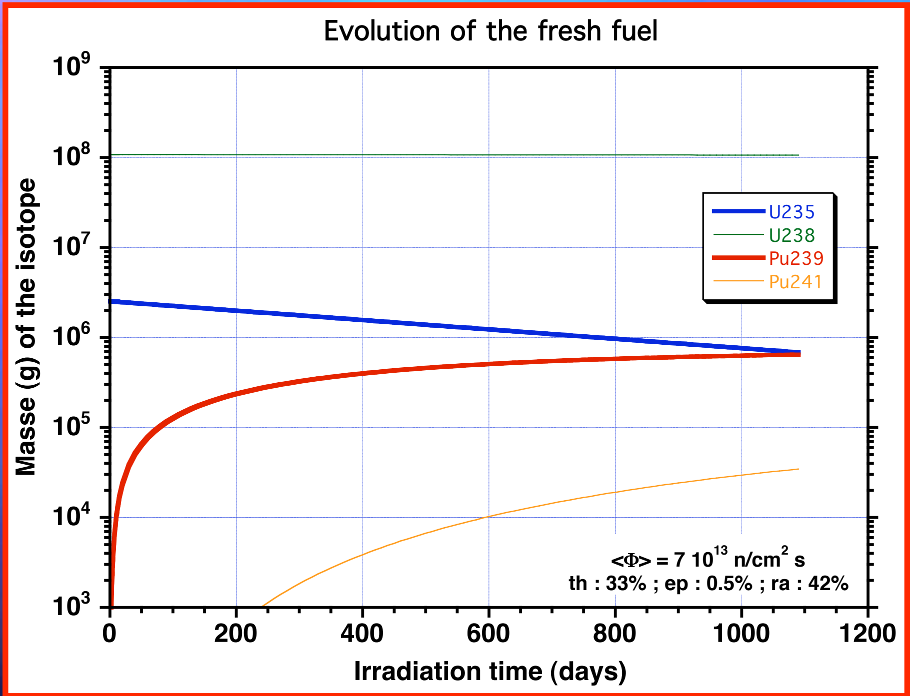
- Safeguard activities :
  - Treaty of NonProliferation (and additional protocole) :
    - accepted (and unattended) controls
  - Detect Diversion from Civil Fuel Cycles to Weapons Programs of Fissile Material (Pu, enriched U)
  - Many places to control all around the world :
    - enrichment units, nuclear fuel factories, power and research reactors, reprocessing units, storage waste…
- Standard methods used
  - mostly checks of input/ouput declarations
  - sampling and analysis (γ-spectroscopy, isotopic content)
  - no direct Pu inventory made at the production place, neither power
- Seeking for new tools to perform future controls on increasing number of installations : ask physicists

Physics basis allowing monitoring

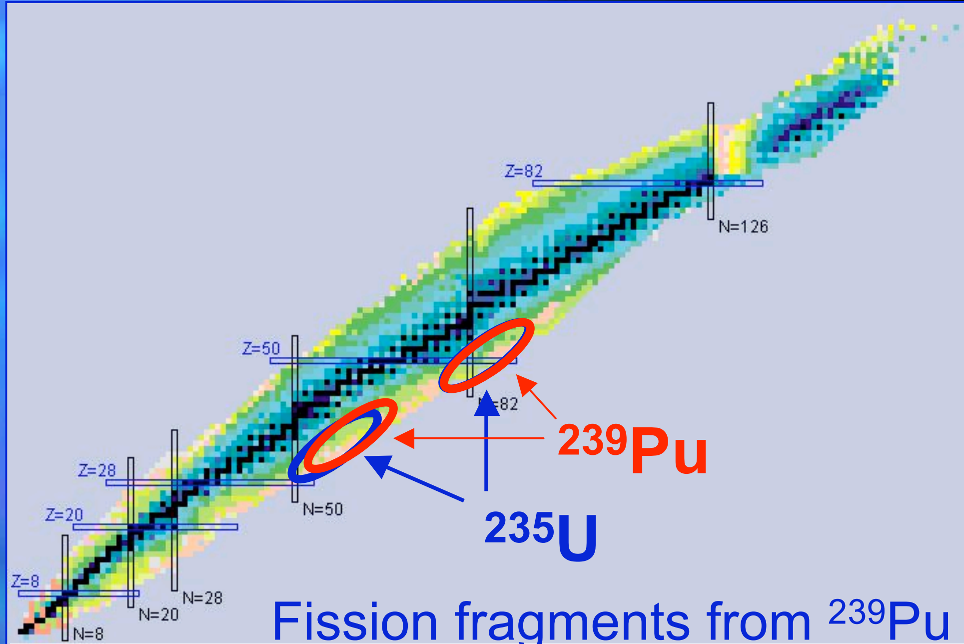
Burn-up & Fission

- ≈ 100 tons 3.5% ^{235}U 96.5% ^{238}U

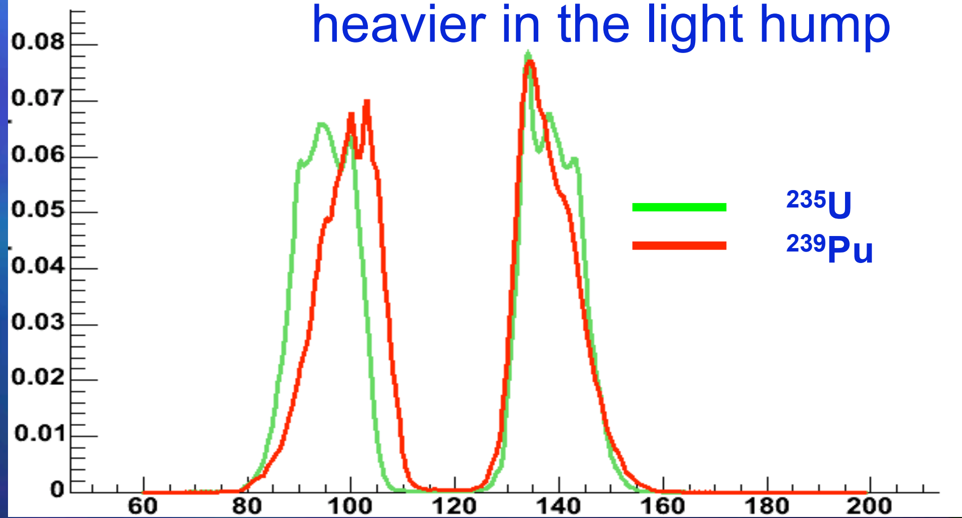
$$^{238}_{92}\mathrm{U} + \mathrm{n} \rightarrow {}^{239}_{92}\mathrm{U} \xrightarrow{23\ \mathrm{min}} {}^{239}_{93}\mathrm{Np} \xrightarrow{2.3\ \mathrm{d}} {}^{239}_{94}\mathrm{Pu}$$



- Grow up of ^{239}Pu during operation
  - ≈ 200 kg of Pu/y/reactor
- ^{239}Pu contribute to energy production

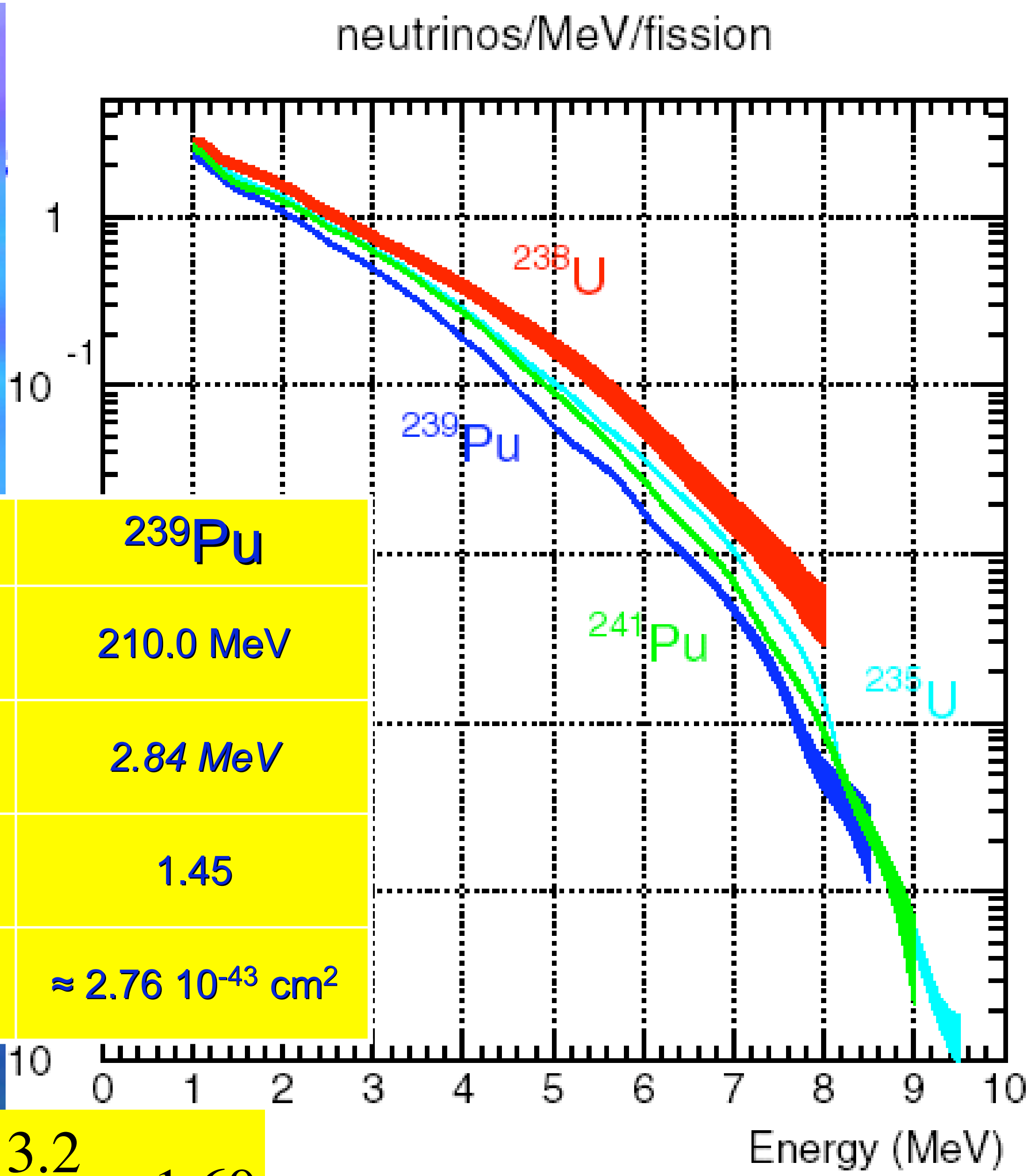


Fission fragments from ^{239}Pu heavier in the light hump



Fission & $\bar{\nu}$

Fission products from ^{235}U or ^{239}Pu are different, hence ν are different



	^{235}U	^{239}Pu
released energy per fission	201.7 MeV	210.0 MeV
Mean energy of ν	*2.94 MeV*	*2.84 MeV*
ν per fission > 1.8 MeV	1.92	1.45
average inter. cross section	≈ 3.2 10^{-43} cm^2	≈ 2.76 10^{-43} cm^2

$$\frac{\# int\ ^{235}U}{\# int\ ^{239}Pu} = \frac{210.0}{201.7} \times \frac{1.92}{1.45} \times \frac{3.2}{2.76} = 1.60$$

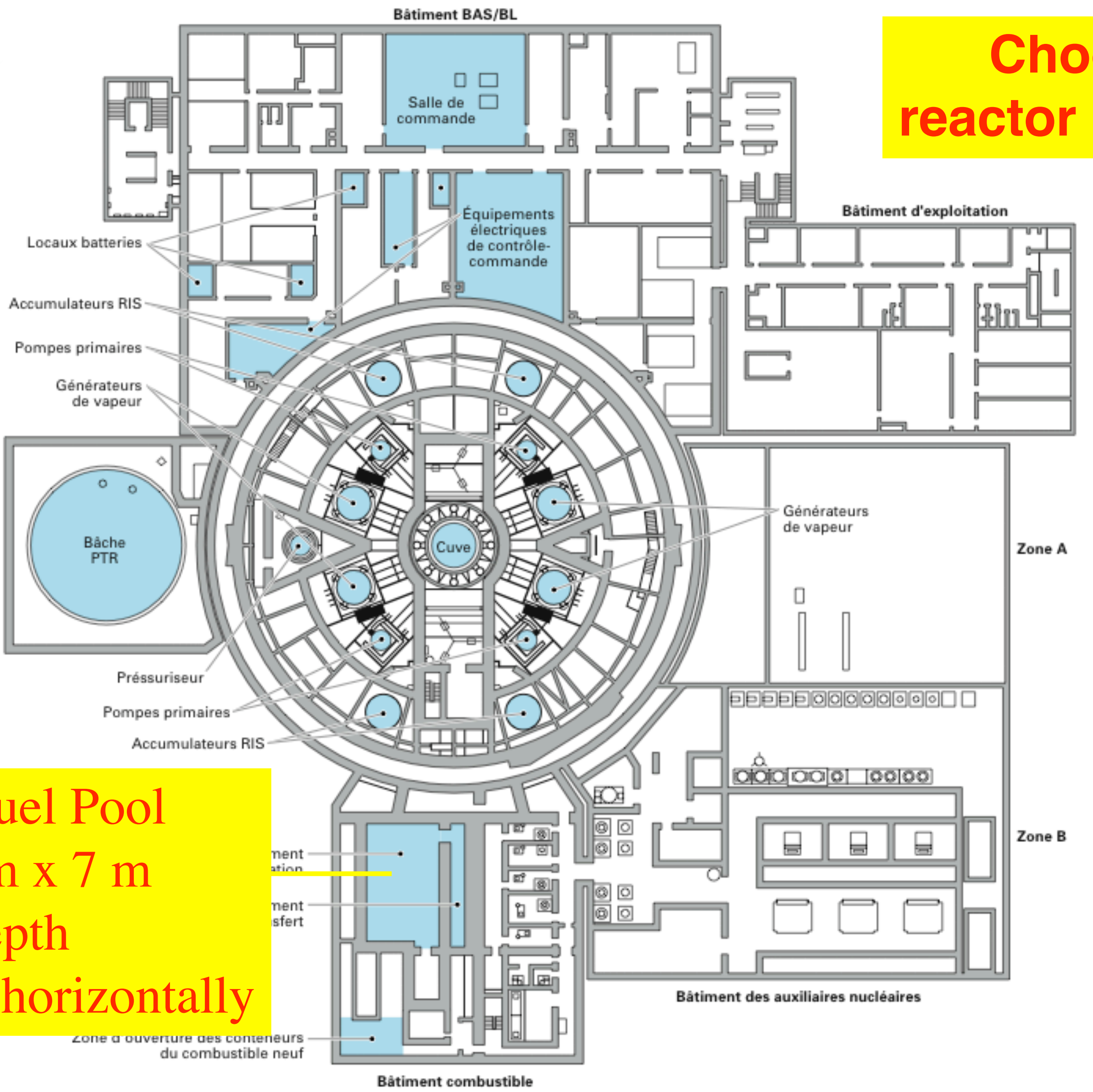
Today's effort in France

Within DOUBLE CHOOZ

The collaboration

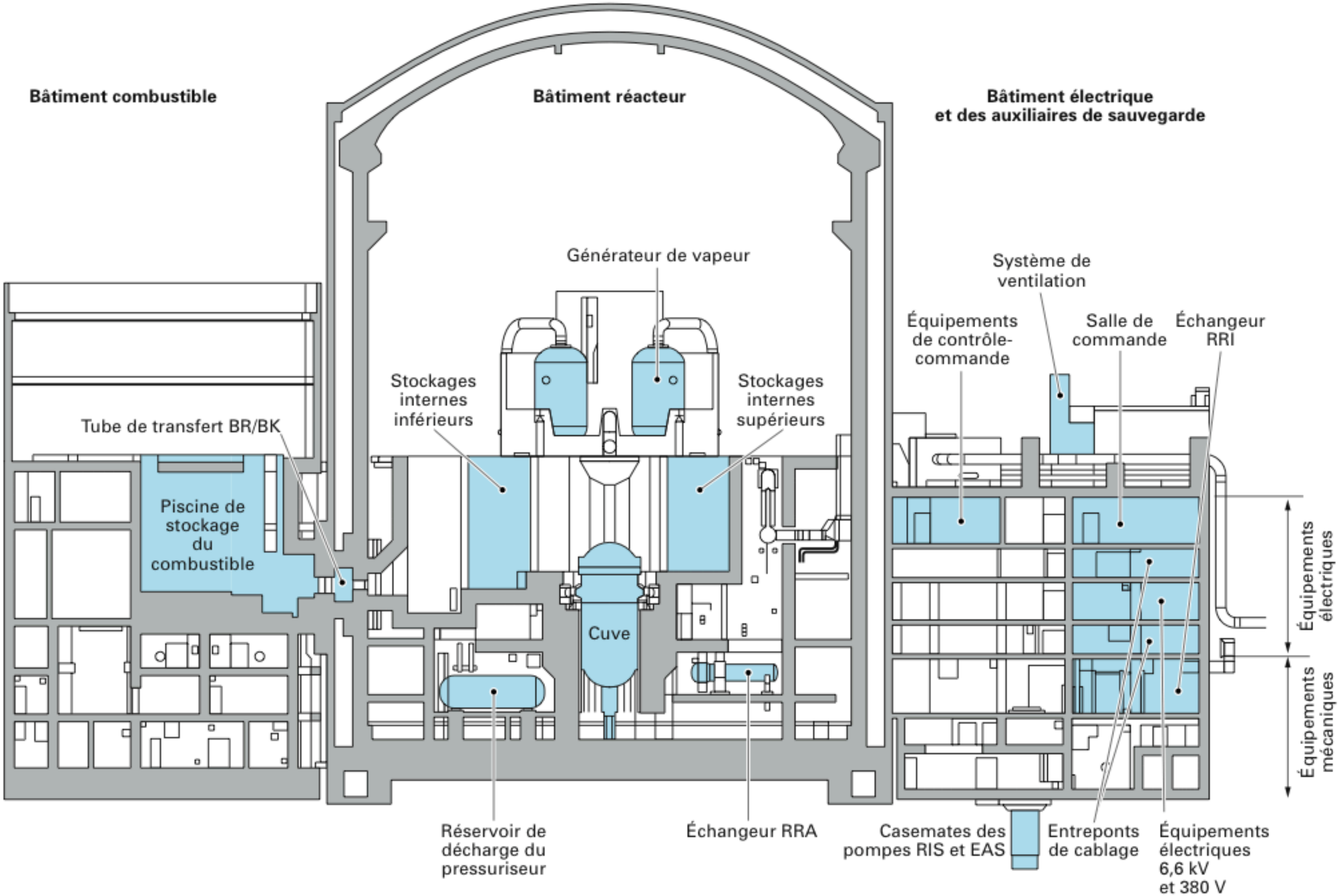
Proposal in June 2006 : hep-ex/0606025
119 authors from 26 institutions

Chooz-B reactor building



10 m

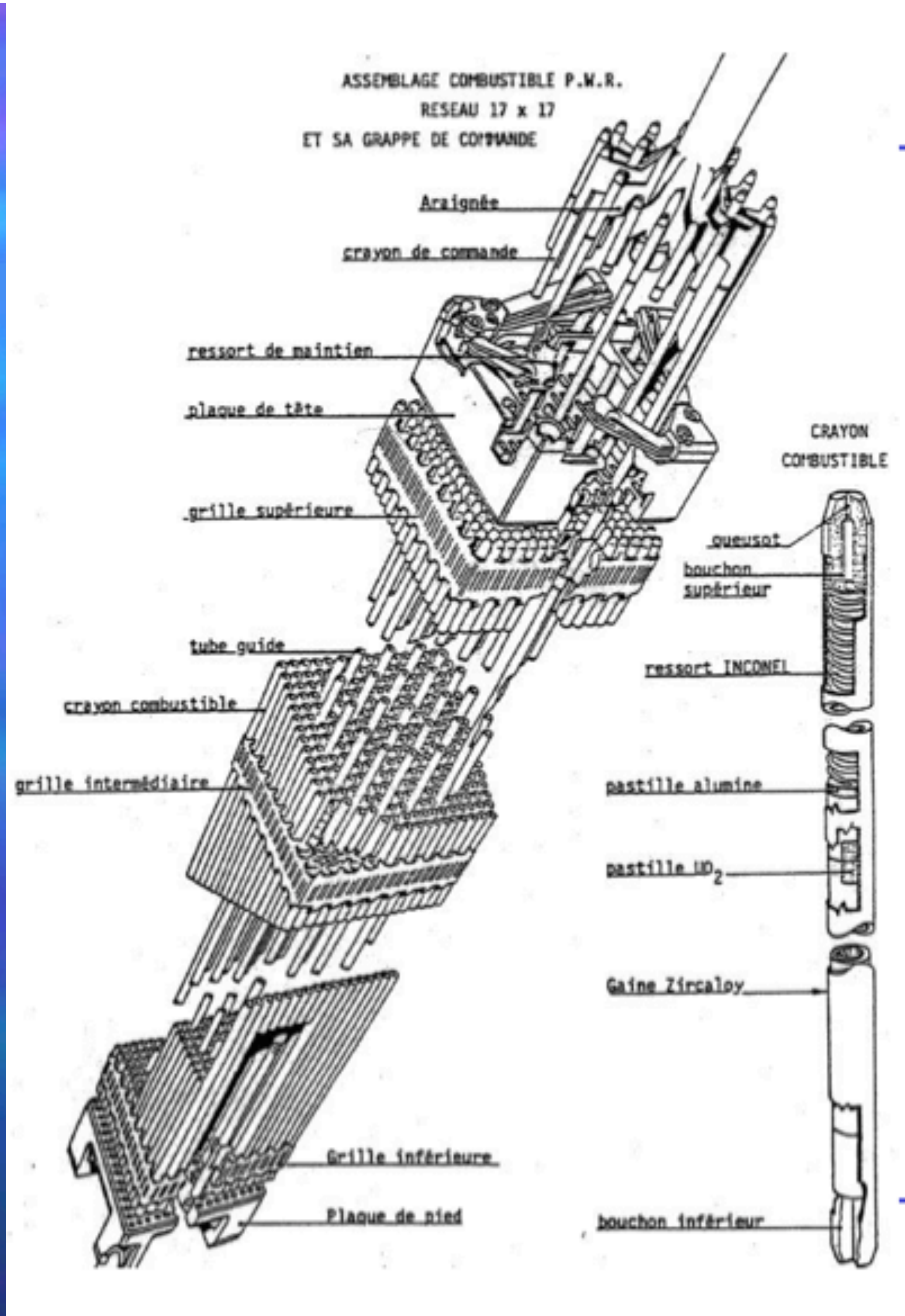
Spent fuel Pool
- 11.5 m x 7 m
-8 m depth
-stored horizontally

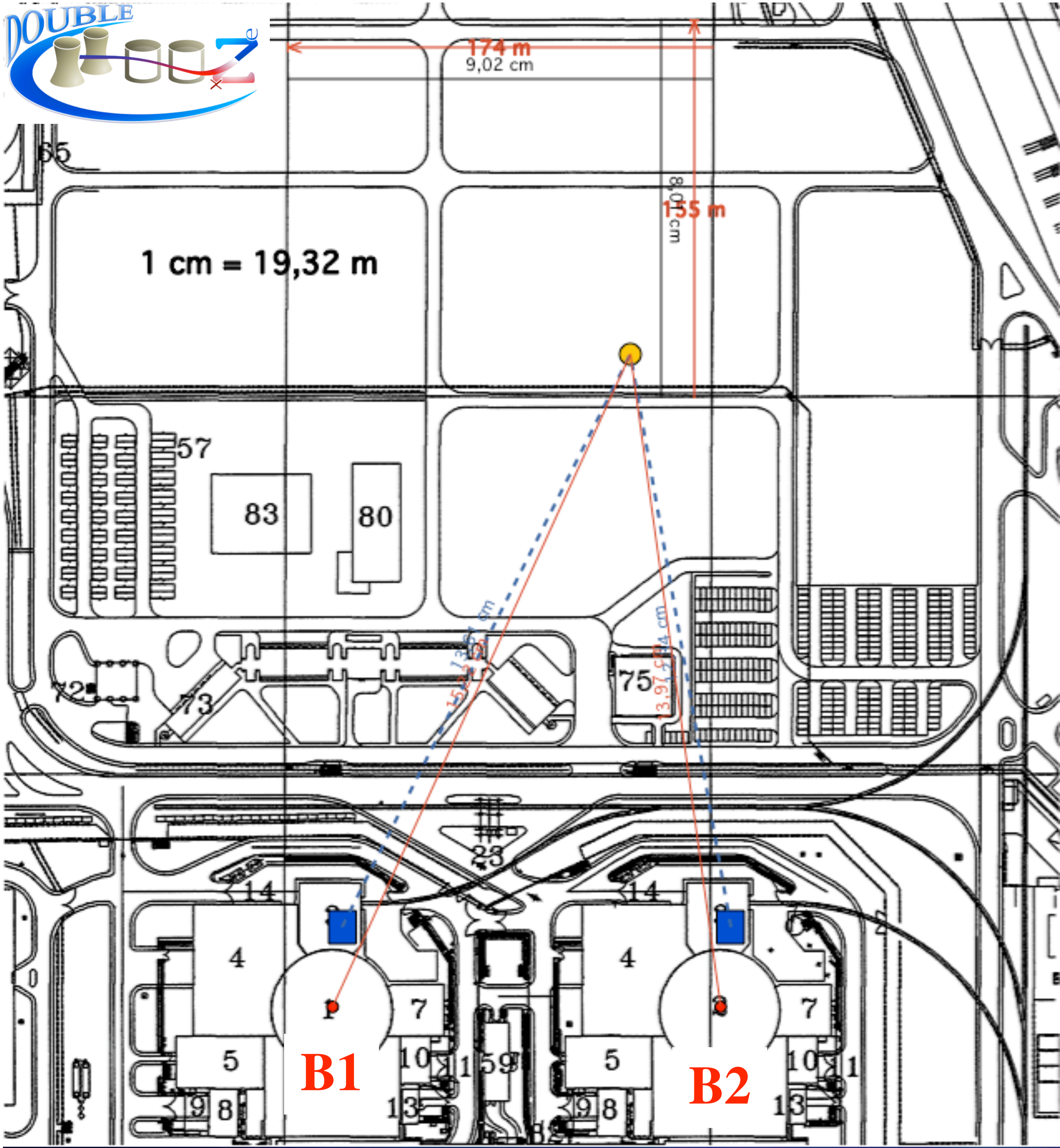

Bâtiment combustible
Bâtiment réacteur
Bâtiment électrique
et des auxiliaires de sauvegarde
Générateur de vapeur
Système de
ventilation
Équipements
de contrôle-
commande
Salle de
commande
Échangeur
RRI
Stockages
internes
inférieurs
Stockages
internes
supérieurs
Tube de transfert BR/BK
Piscine de
stockage
du
combustible
Cuve
Équipements
électriques
Équipements
mécaniques
Réservoir de
décharge du
pressuriseur
Échangeur RRA
Casemates des
pompes RIS et EAS
Entreponts
de cablage
Équipements
électriques
6,6 kV
et 380 V

Few numbers

- Fuel in N4-reactors
  - 120 tons of UO_2
  - 105.7 tons of enriched U
  - $^{235}U \approx 3.45\%$: 3.60 tons
- 205 fuel assembly
  - 264 rods per assembly
  - 272 "*pastilles*" per rods
  - 8 g per "*pastilles*"
- Loading/unloading
  - by quarter
  - every 8 months or 12 ?
- Yearly elect. energy
  - $4.7\ 10^{16}$ J = 13 TW.h
  - 34.4 % efficiency (th->el.)
- Nominal energy extracted from fuel
  - 45 GWd/ton = $3.89\ 10^{15}$ J/tons*

    * *tons of enriched Uranium*





Distances in meters

from G. Mention

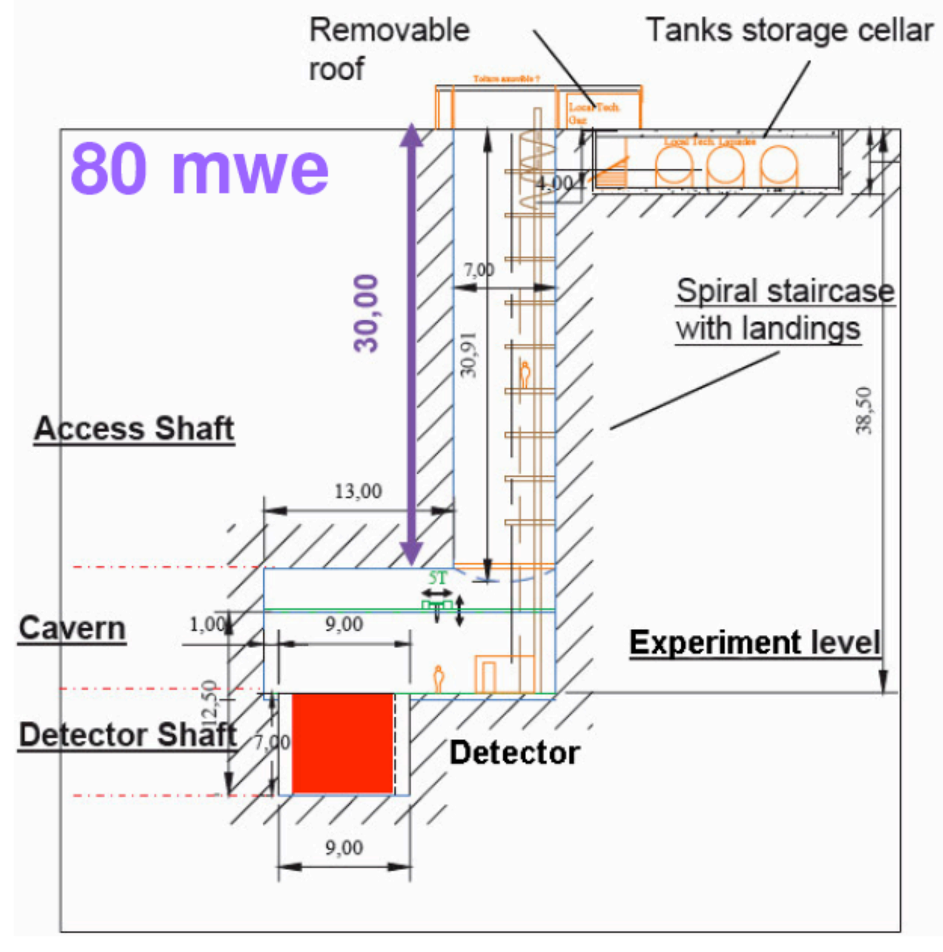
near detector

	B1	B2
core	293.5	263.4
pool	259.0	224.3

Far detector

	B1	B2
core	1114.7	998.0
pool	1141.8	1028.1

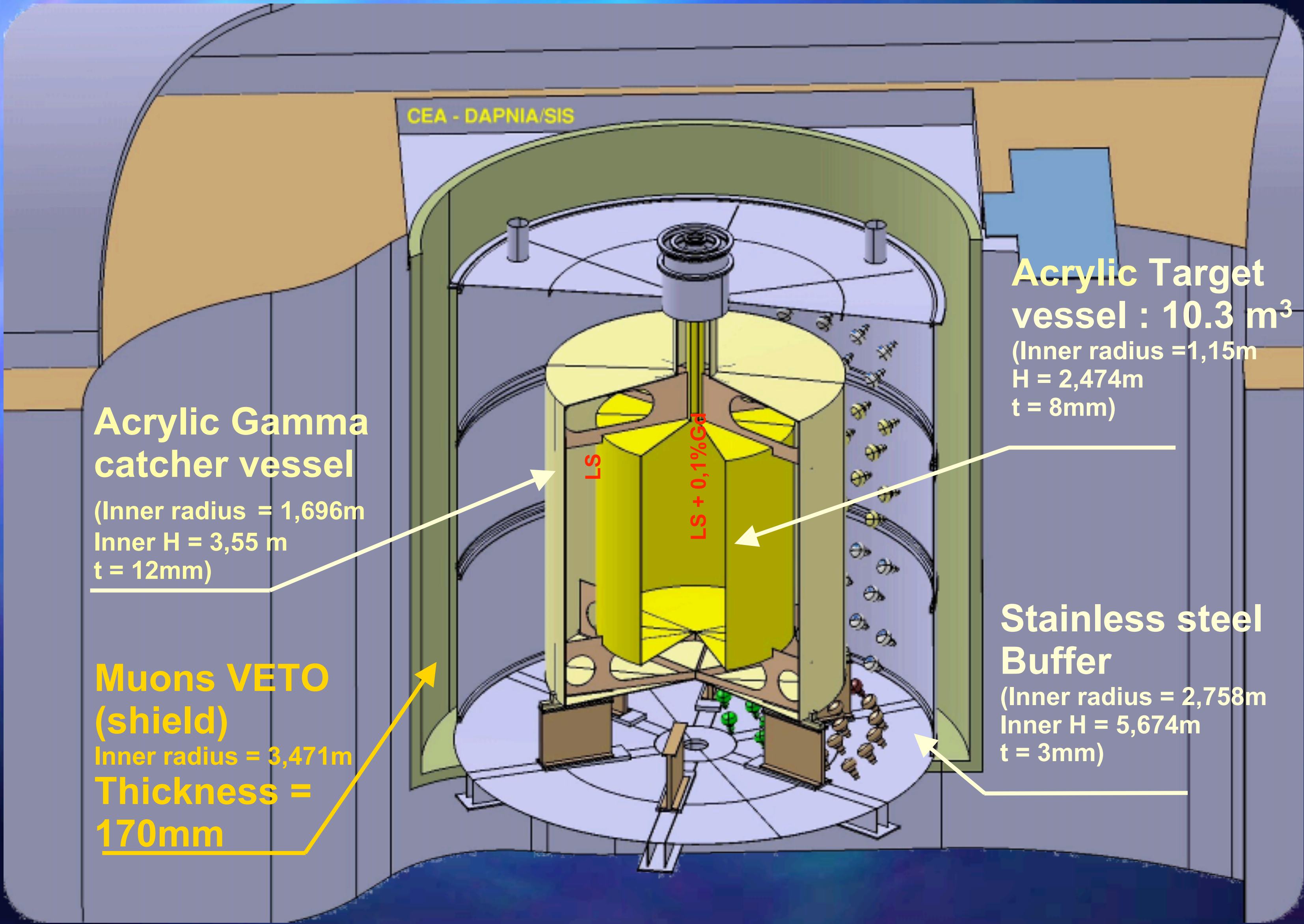
The near laboratory



- ≈ 45 m deep shaft
- a cavern
- overburden ≈ 80 mwe
- to be built in cooperation with EDF
- ready in 2009

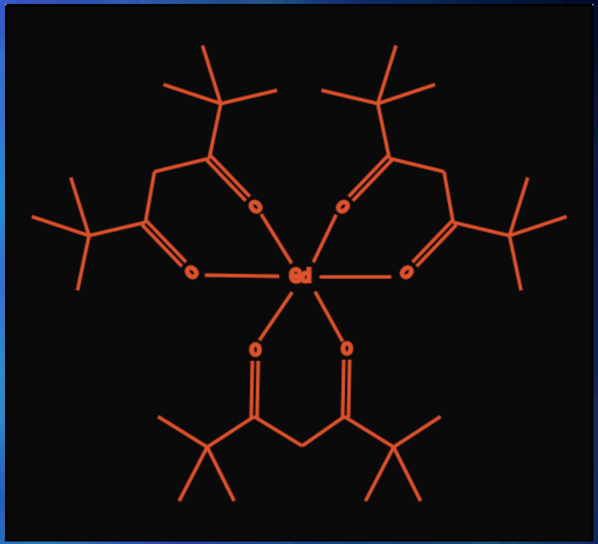
Detector layout

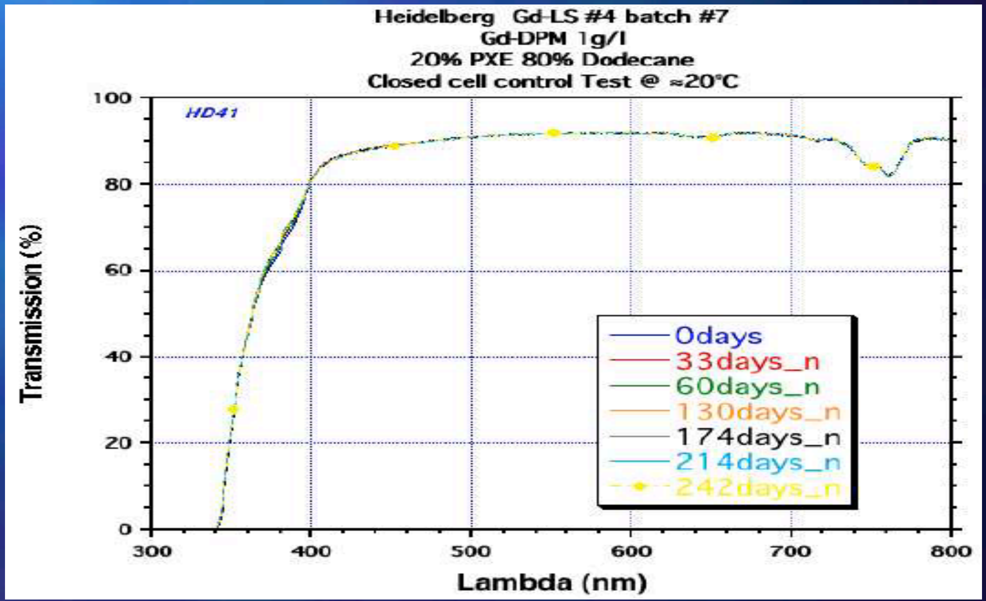
Detector dimensions have been frozen



Gd-loaded liquid scintillator

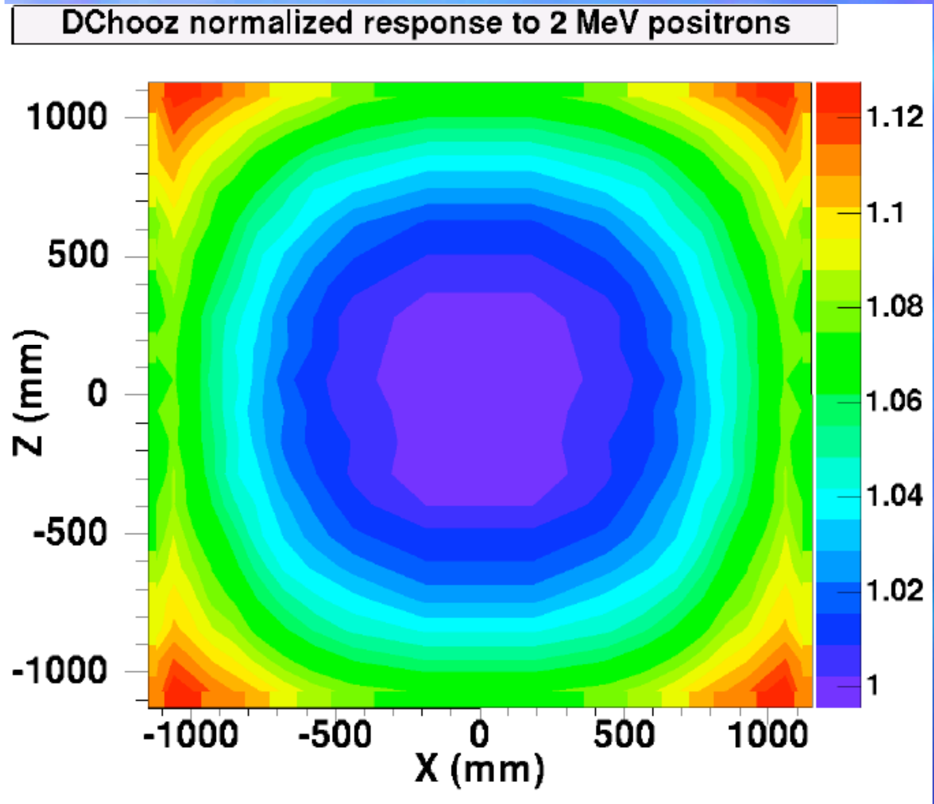
- Scintillator : compatibility and safety
  - 20% PXE + 80% Dodecane + PPO (≈ 6 g/l) + bis-MSB (≈ 20 mg/l)
- Gd-compound (1 g/l)
  - Gd-CBX + stabilizers
  - Gd-DPM
- Test with 100 liters mock-up
- Production into pre-industrial phase

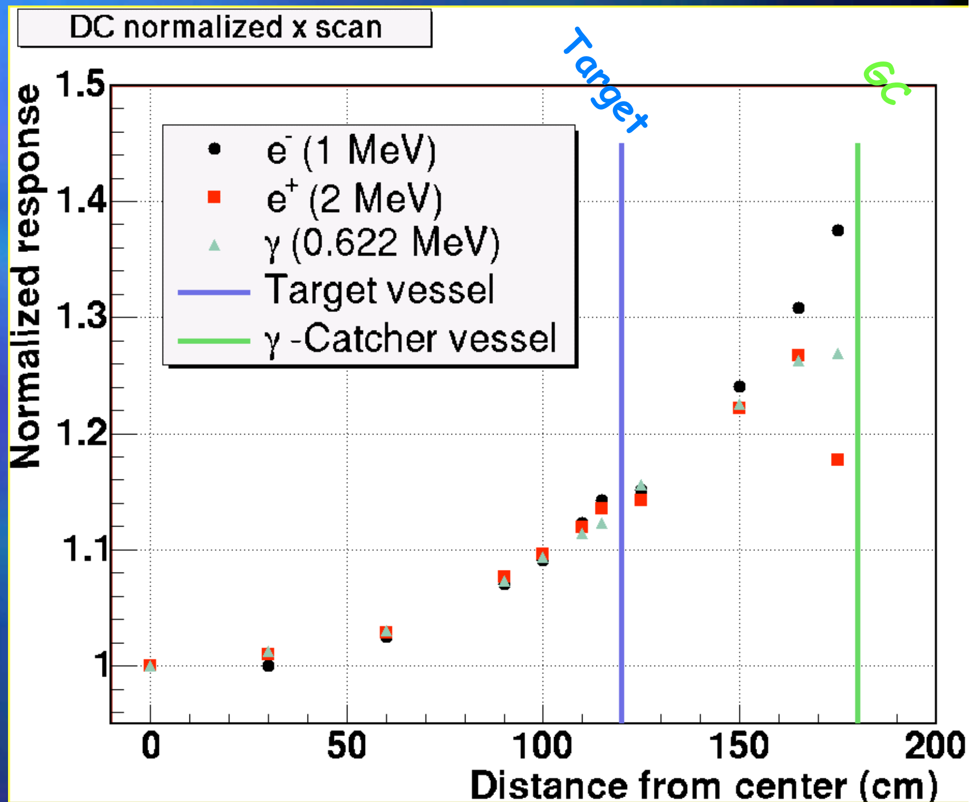




Detector response

❖ 534 PMTs 8' : 13% cover.

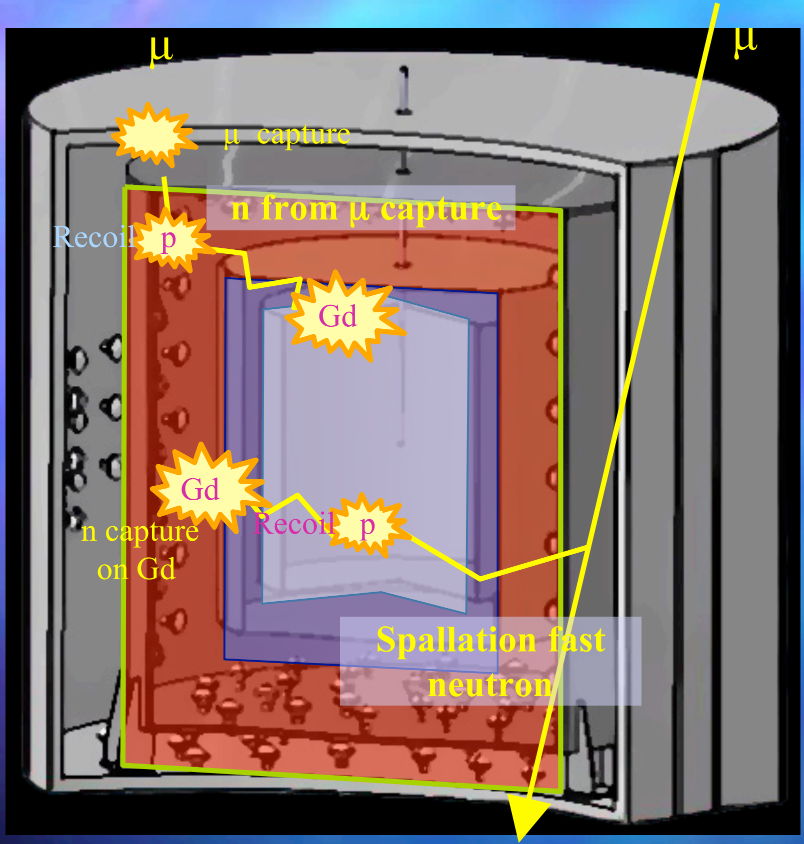




❖ Modest variations within target volume

❖ Good energy reconstruction

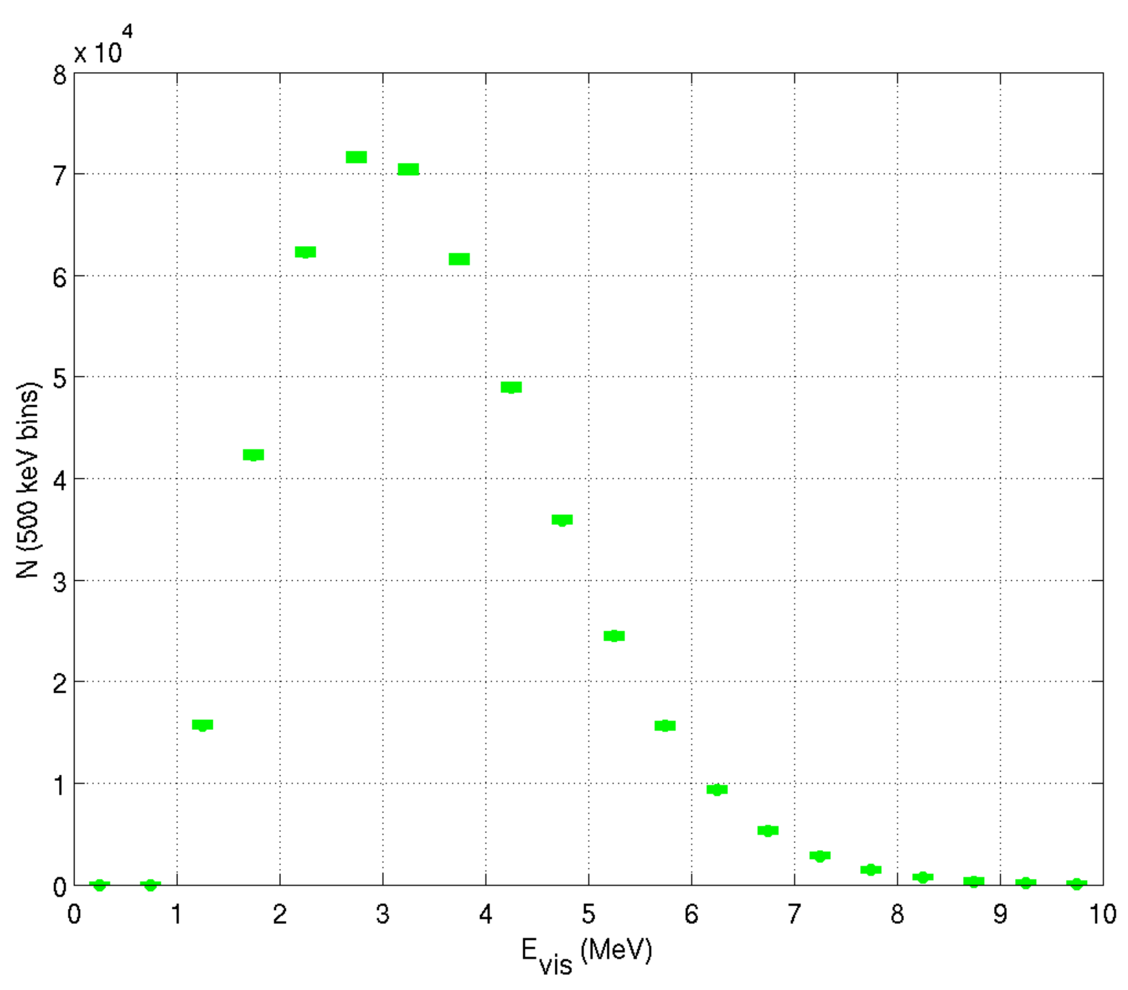
μ-induced background



- To be compared to
  - 990 ν_e per day

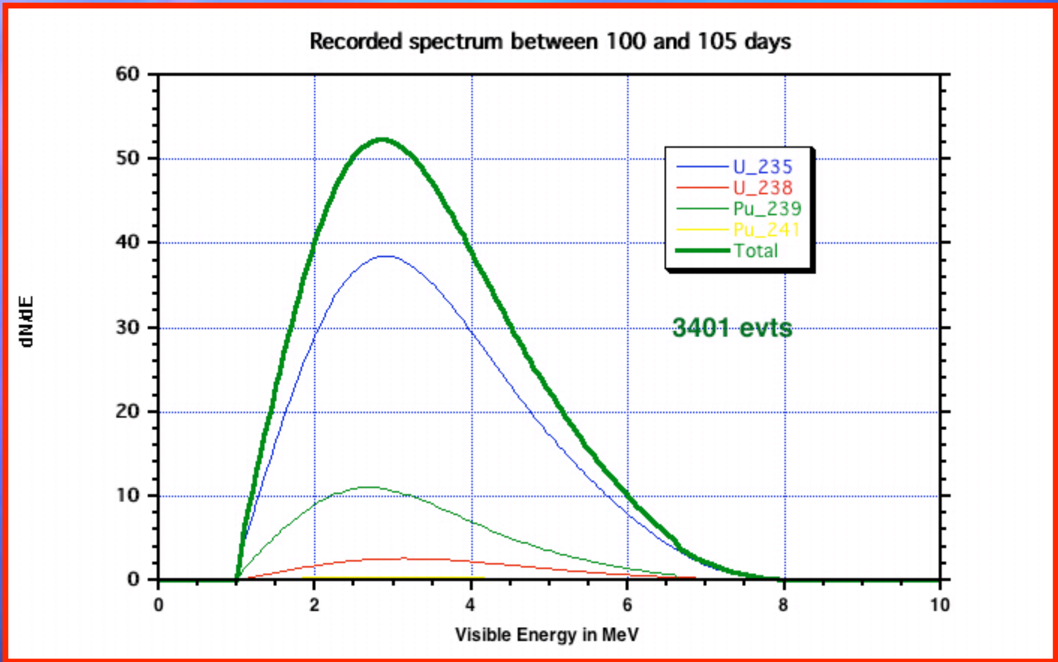
- Fast neutrons + μ-capture
  - Geant + Fluka
  - Reliable : reproduce old Chooz bkg rate
  - rate @ near det. < 6/d
- Accidental
  - single from PMTs
  - neutron from μ cosmique
  - rate @ near det. < 15/d
- Cosmogenic ^{9}Li
  - rate @ near det. : 5.3 ± 3.2 /d
- Outer veto to sign near-missed μ

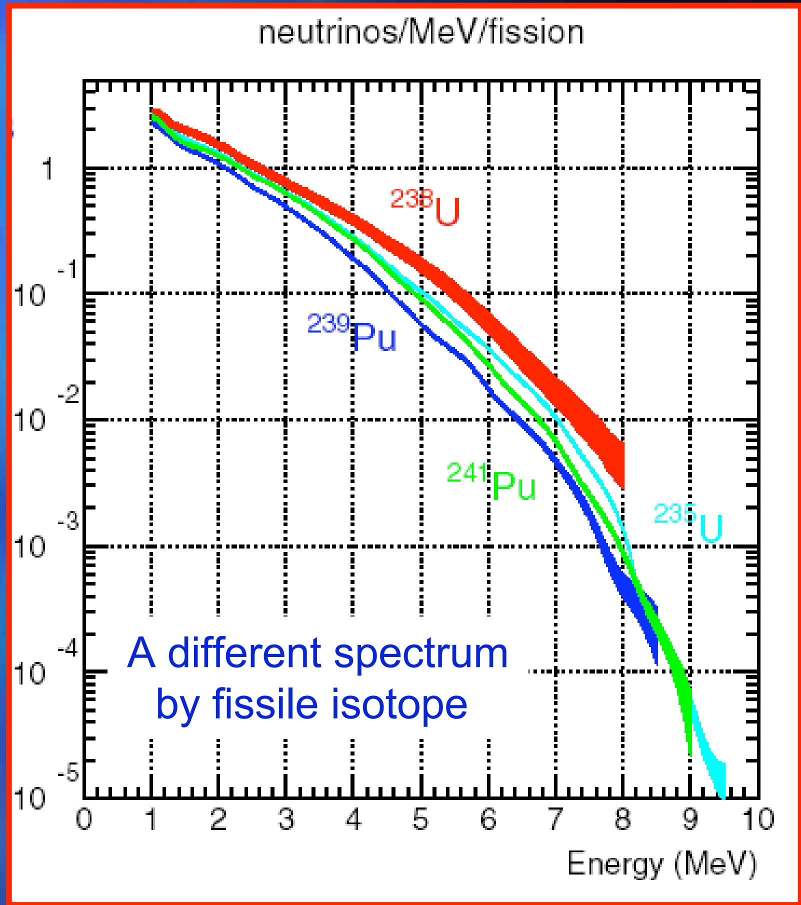
A high statistic experiment



- Target : 10.3 m^3
- Detect. effic. : 80%
- Dead time : 30%
- Rate with eff. : 554 /d
- 3 years of data taking
  - 157 000 evts/years

Fuel composition from ν recording ?

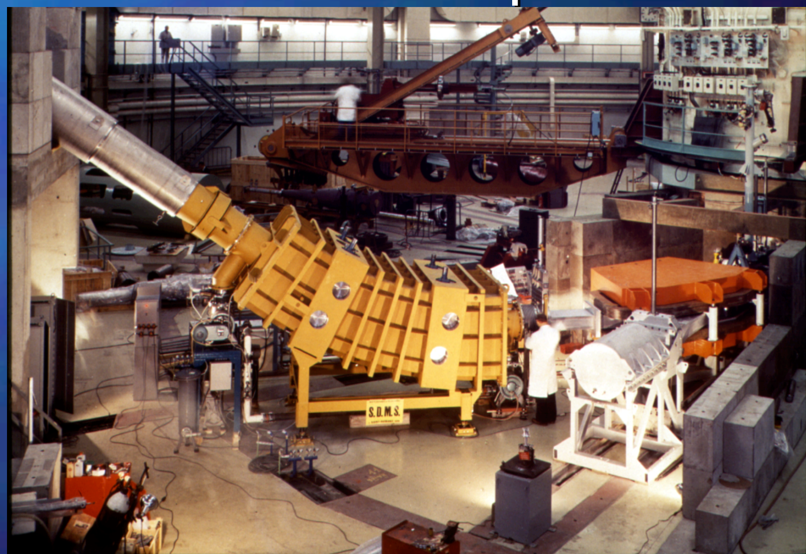




- Fit the positron spectrum
  - % ^{235}U, ^{239}Pu,…as free parameters
  - use known different shapes (paramet.)
  - possible but modest precision ≈ 10 % ^{239}Pu content
- Need to reduce errors (1/3) on ν spectrum to achieve few % precision on Pu, *P. Huber & T. Schwetz, hep-ph/0407076*

A comprehensive effort

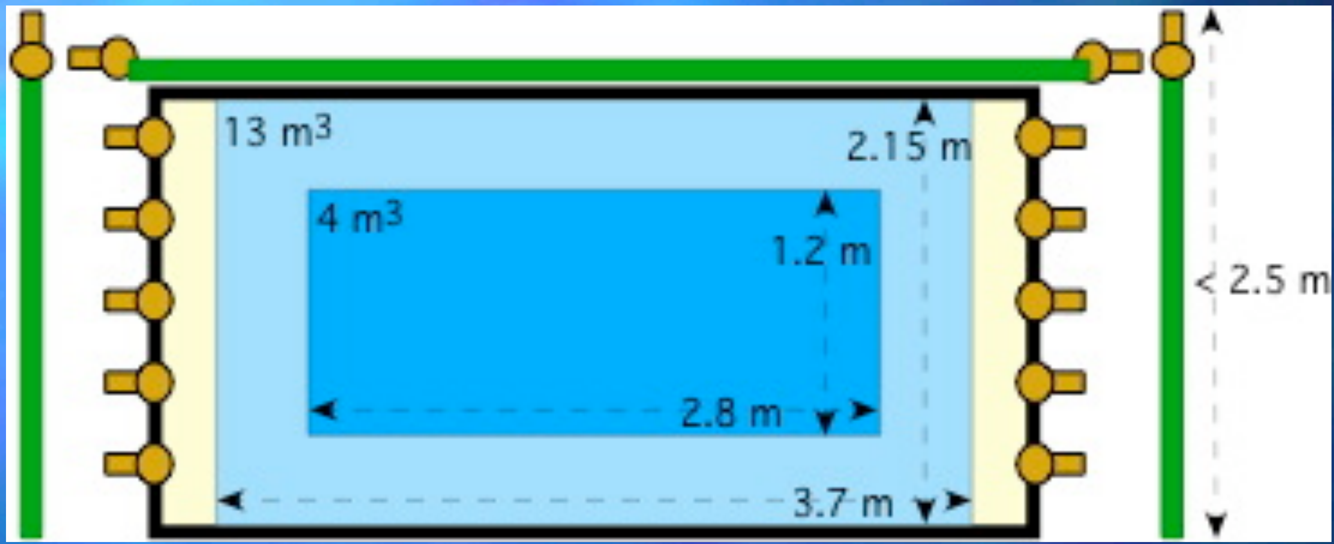
- Precise ν spectrum vs fissile element (^{235}U, ^{239}Pu) :
  - high statistic with Double Chooz (near) : 1.6×10^5 ν detected per year
  - correlation with fuel composition, with thermal power
  - At least a valuable database
- Simulations of the fuel evolution
  - use MURE : interface MCNP (static reactor code) and evolution code
  - include diversion scenarios : predict neutrino signature
- Critical evaluation of ß decays spectrum from fission products
  - concentrate on high energy tails
    - large uncertainties due to multiple excited states
    - place to discriminate ^{235}U vs ^{239}Pu fissions most clearly
- New experimental program at ILL*
  - Lohengrin spectrometer
  - *see Muriel's talk*



* Institut Laue-Langevin (Grenoble)

Toward a prototype of monitor

- Double Chooz approach
  - good energy measurement
  - good signal/noise
  - too sophisticated
  - expensive

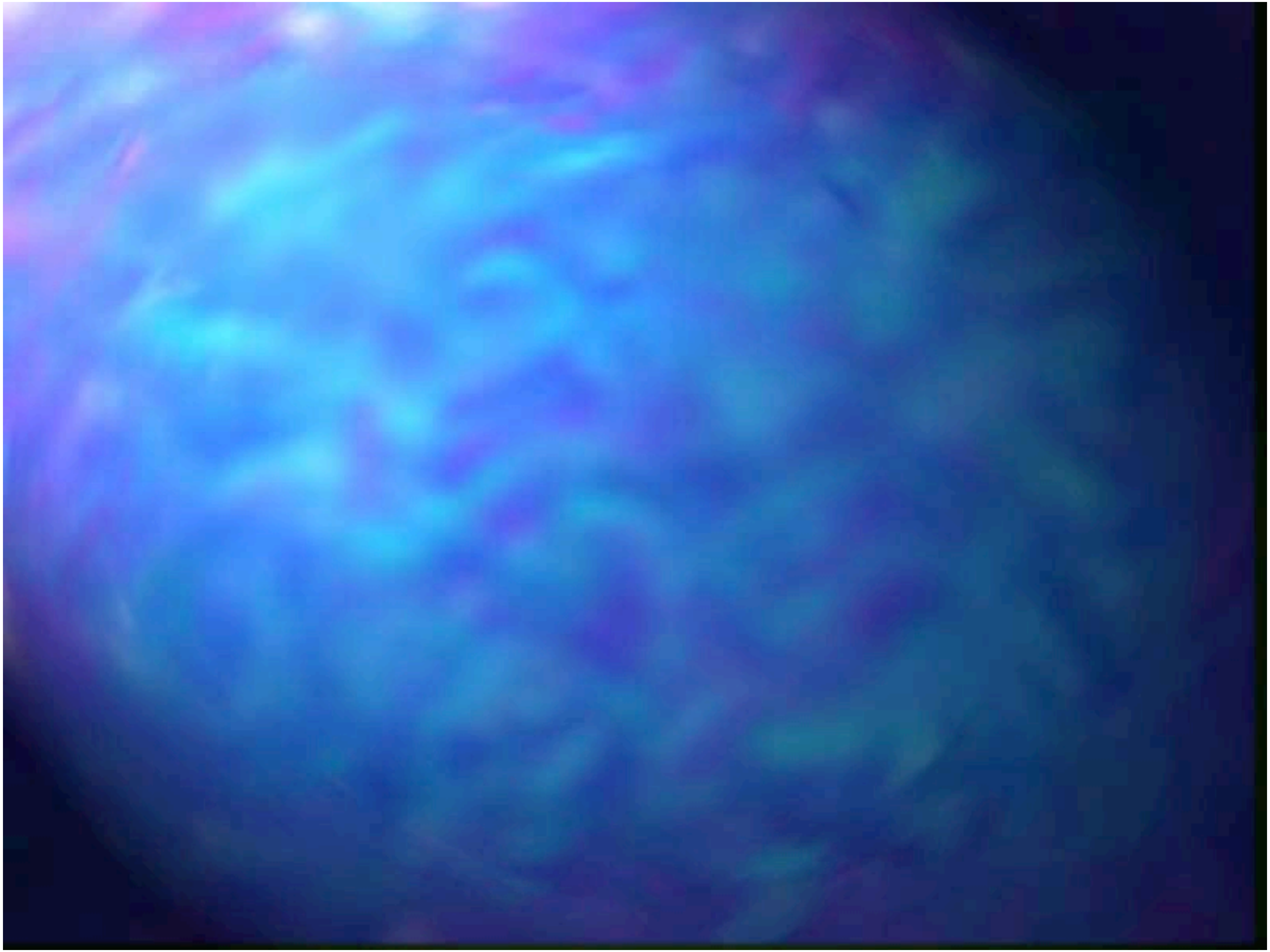


- Songs approach
  - weak ν signature
  - not enough rejection of background
  - robust, simple operation
  - automatic
  - cheap

see Thierry's talk

Conclusion

- Double Chooz for θ_{13}
  - construction of far detector will begin next spring
  - an impressively strong collaboration
- Nonproliferation activities within Double Chooz
  - embedded since the beginning
  - induce specific developments
    - neutrino spectrum (simulation and measurements)
    - thermal power prototype
  - attract specifically several groups



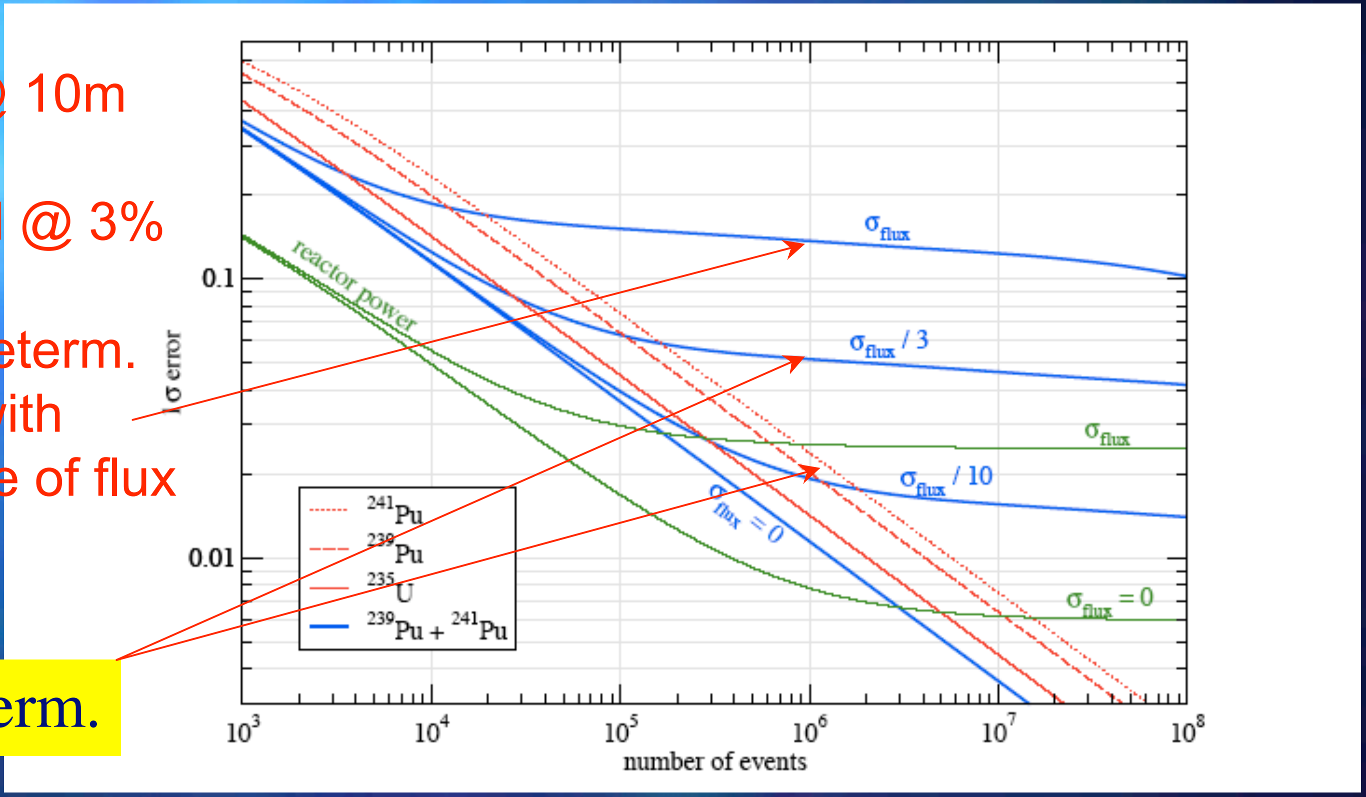
Extra slides

What is the precision required ?

P. Huber & T. Schwetz, hep-ph/0407076,
Precision spectroscopy with reactor antineutrinos

10^6 evts : 10 tons @ 10m
in 10d
Power determ. in 1d @ 3%

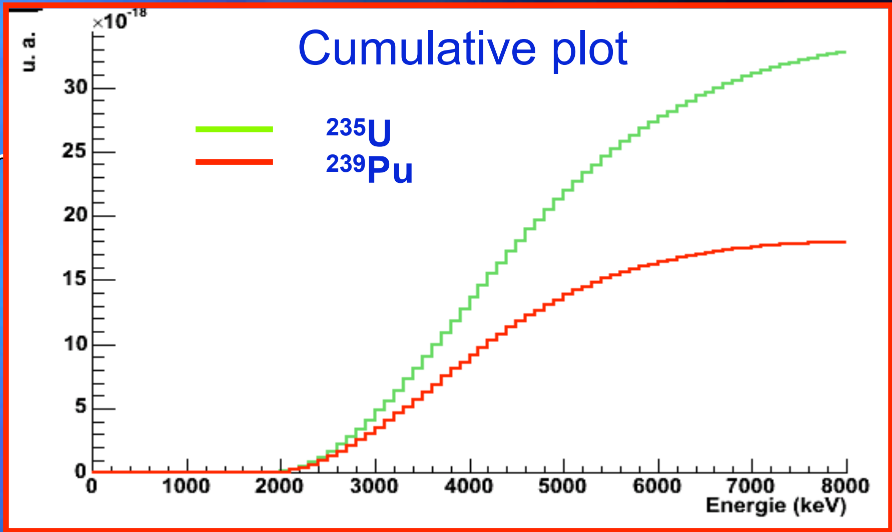
Pu content poorly determ.
@ > 10% in 10d with
present knowledge of flux



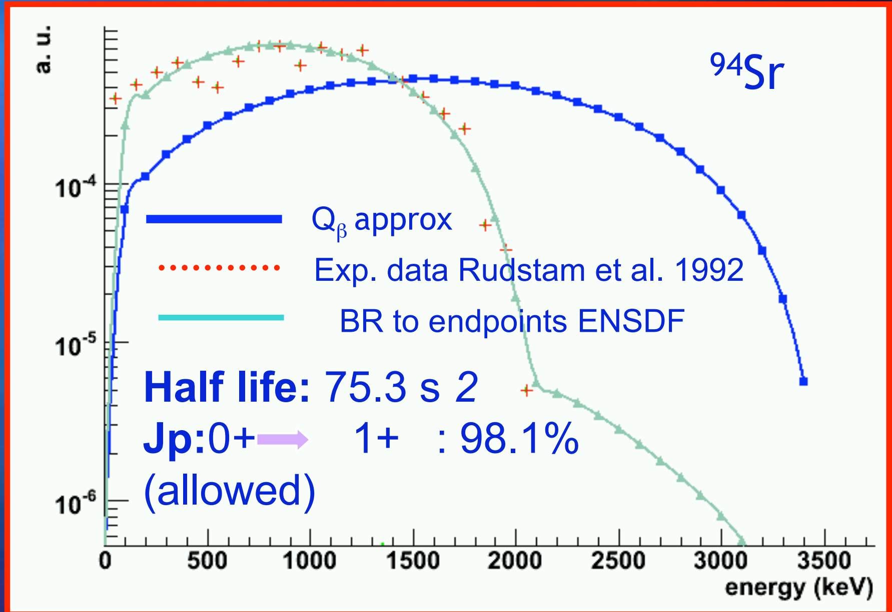
Improve flux determ.

The high energy limit

- Previous ν spectrum studies
  - *Schreckenbach et al.* *PLB (1989) 325-330*
    - problems in converting ß to ν spectrum
  - *Tengblad et al.* *NPA (1989) 136-160*
    - Above 4 MeV : errors increase (5% at 4 MeV, 20% at 8 MeV)
  - *C. Bemporad et al.* *RMP.74 (2002)* :
    - " 25% of high energy part due to experimentally unknown exotic neutron-rich nuclei "

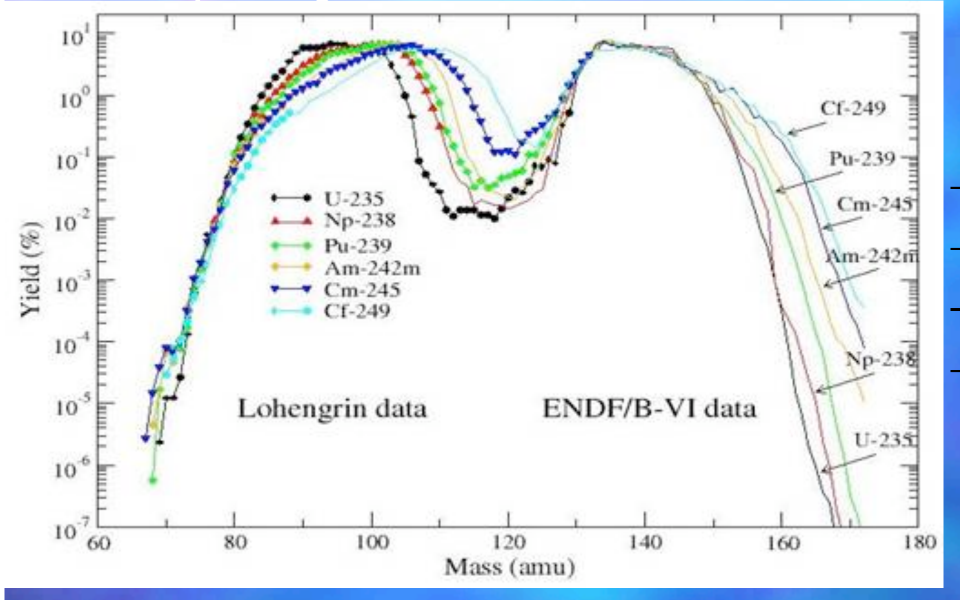


- Role of the excited levels
  - Simulation : identification of unknown nuclei of interest : *ie* contributors and/or discriminating ^{235}U/^{239}Pu)
  - Build exact spectrum
  - Include type of transition allowed/forbidden



Test experiment @ Institut Laue-Langevin High Flux Reactor (Grenoble)

Facility : High-Flux 58.4 MW Reactor



- Neutron flux ~5.10^{14} n cm^{-2} s^{-1}
- Fission rate ~ 10^{12} fissions/s at target
- ~ 300 ^{132}Sn/s at focal point
- Fission yields depend on target (Np to Cf)

Use of the LOHENGRIN (PN1) online mass spectrometer for unslowed fission products : separates neutron-rich nuclei far from stability

Ions are separated according to their A/q values